Non-Proliferation and Nuclear Safeguards

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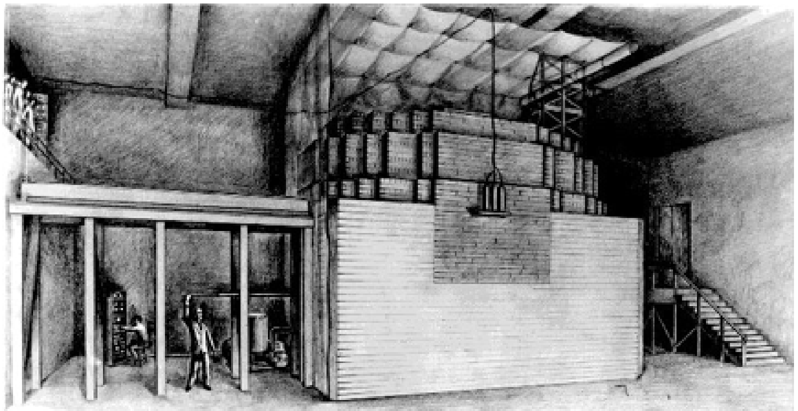
Overview

- Why safeguarding nuclear material?
- Historical overview (NPT and Euratom Treaty)
- Principles of Nuclear Safeguards
- Inspection techniques for NMAC
  - Nuclear measurements (DA and NDA)
  - Containment and surveillance
- Inspection techniques for AP
  - Environmental sampling
  - Remote sensing and satellite imagery
  - Open source analysis

Why safeguarding nuclear material

1942, Dec. 2nd: Enrico Fermi runs the Chicago pile CP1

the first self-sustained nuclear chain reaction



1945, Aug. 6th:

The first atomic bomb

is dropped on Hiroshima

Historical overview: International Safeguards

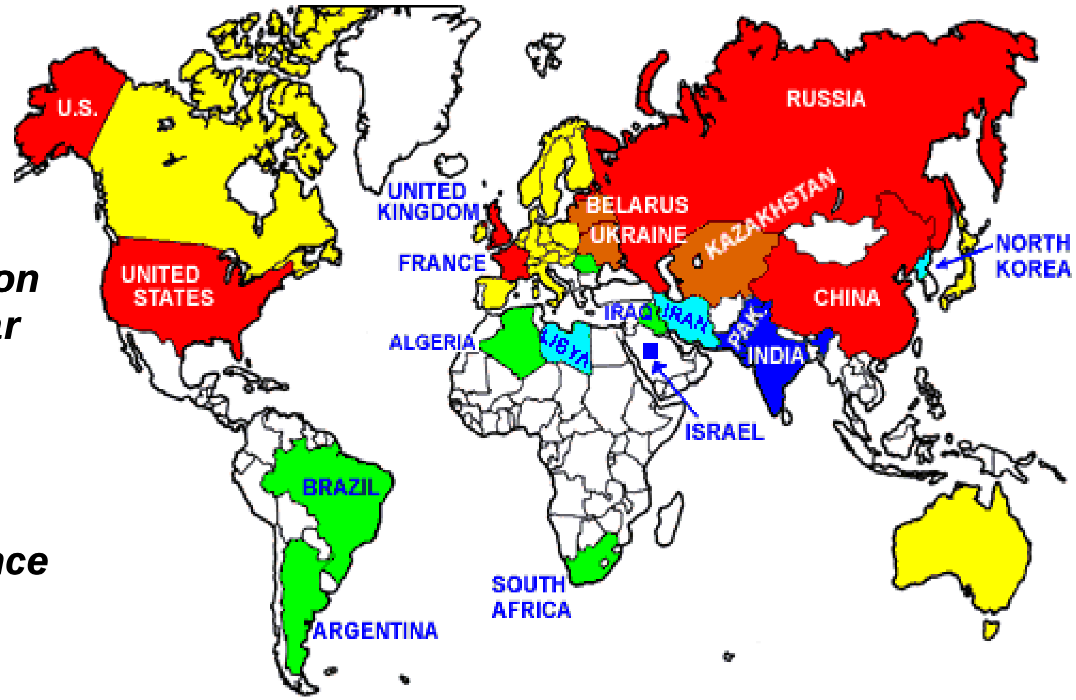
- 1953: US President Eisenhower launched the initiative "Atoms for peace"
- 1957: International Atomic Energy Agency starts to operate
- 1961-1968: Implementation of first safeguard systems
- 1970: Signature of Non-Proliferation Treaty (1970)
- Weaknesses and failures of NPT:
  - 1974: India manufactures his first nuclear weapon, then followed by Pakistan
  - 1990: the Iraq case
  - 2003: North Korea breaches the NPT
  - 2006: GCEP operation in Iran
- From traditional to integrated safeguards: the Additional Protocol (1995)

Historical overview: NPT

INFCIRC/153 (1972) establish a Safeguard System according to the principles stated by NPT

Objective of safeguards

"…the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."



Nuclear material accountancy and control (NMAC) is the main pillar of safeguards according to INFCIRC/153

Containment & Surveillance as complementary measure

Historical overview: IS and AP

Objective of Integrated Safeguards:

- Absence of undeclared activities in declared plants
- Absence of undeclared facilities

INFCIRC/540 (1997) implements the concept of IS in the countries signing the Additional Protocol

Historical overview: Euratom Treaty

1957, March 27th: 6 countries (nowadays 25) sign the Euratom Treaty

Objective of the Treaty was the promotion of use of nuclear energy

Chapter VII: Safeguards

> **"...*the Commission shall satisfy itself that:***
>
> ***(a) ores, source materials and specific fissile materials are not diverted from their intended use as declared by the users;***
>
> ***(b) ... safeguarding obligations assumed by the Commission...are complied with*."**

Principles of Nuclear Safeguards

States having signed the NPT accepts to be subjected to IAEA inspections

IAEA concentrates its ***"…** verification procedures on those stages of the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons* ***…*** *could readily be made**…"***

Inspections are aimed to verify:

- the respect of the plant design according to the information provided to the Agency (DIV)
- the plant operator keeps an adequate inventory of the nuclear material (control of records)
- correctness and completeness of the declared inventory through independent measurements (PIV)

Principles of Nuclear Safeguards

Material categories

Nuclear material
Direct use material (fresh Pu, ^{233}U or HEU)
Irradiated direct use material
Indirect use material (LEU, nat U, depl U or Th)
Non-nuclear material
Heavy water, Deuterium
Zircaloy tubes
Nuclear grade graphite

Principles of Nuclear Safeguards

Timely detection

Timeliness criteria

- Time within which a diversion of 1 SQ should be detected
- Order of magnitude time needed for conversion into weapon-grade material

Direct use material (fresh Pu or HEU)	1 month (+ 1 week)
Irradiated direct use material	3 months (+ 3 weeks)
Indirect use material (LEU, nat U or Th)	1 year (+ 2 months)

Principles of Nuclear Safeguards

Significant Quantity:

approximate amount of NM for one nuclear weapon

Pu, ^{233}U	8 kg
HEU	25 kg ^{235}U
LEU	75 kg ^{235}U
Nat U	10 tonnes
Dep U or Th	20 tonnes

Principles of Nuclear Safeguards

Diversion strategies

- Sudden diversion
- Diversion protracted in time
- Diversion via gross defects
- Diversion via many small diversions

Gross defect test	Go-No Go
Partial defect test	Quantity measurement
Bias defect test	Best available method

Principles of Nuclear Safeguards

Establish counter strategy (sampling plan)

- Item counting
- Verification by measurement
  - Verify no diversion via gross defects
    (Fast measurements on many samples)
  - Verify no diversion via small defects
    (Accurate measurements on a few samples)
- Random, Short Notice inspections

Safeguards inspection techniques

Nuclear material accountancy:

- Pu, HEU, LEU in gram
- Natural and depleted U, Th in kg

- Weighing
- Volume determination
- Item counting
- Non-destructive analysis
  - Gamma-spectrometry
  - Passive and active neutron counting
  - Calorimetry
- Destructive analysis
  - Mass spectrometry
  - Concentration measurement

Continuity of knowledge:

- Containment & Surveillance
  - Seals
  - Cameras

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Nuclear measurement techniques for NMAC

	DA	NDA
Type of item	sub-sample of mat.	entire item in cont.
Meas./processing time	days to months	minutes to hours
Sample throughput	~1/day	~10/day
Typical accuracy	~0.1%	few %
Target	Bias defect	Partial defect

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Destructive Analysis (DA)

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Purpose:

To measure mass and isotopic composition of NM samples taking and analysing small sub-samples

Principle:

Use chemical or physical/chemical techniques after proper conditioning of the sample (dissolution, dilution, spiking,…)

- Chemical methods for concentration determination:
  - Electrochemical methods (titration, coulometry,…)
  - Gravimetry
  - Isotope Dilution Mass Spectrometry (IDMS)
- Measurement of isotopic composition:
  - Mass spectrometry (TIMS,…)

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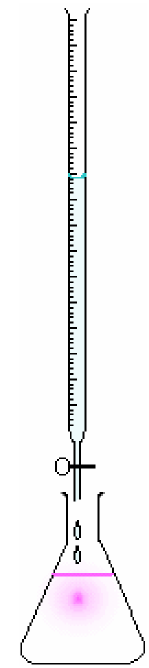
Destructive Analysis (DA)



Titration:

Determination of the concentration of an unknown reagent using a standard concentration of another reagent that chemically reacts with the unknown.

In potentiometric/amperometric titration the reaction end-point is determined by measuring the solution conductivity.

Mass spectrometry:

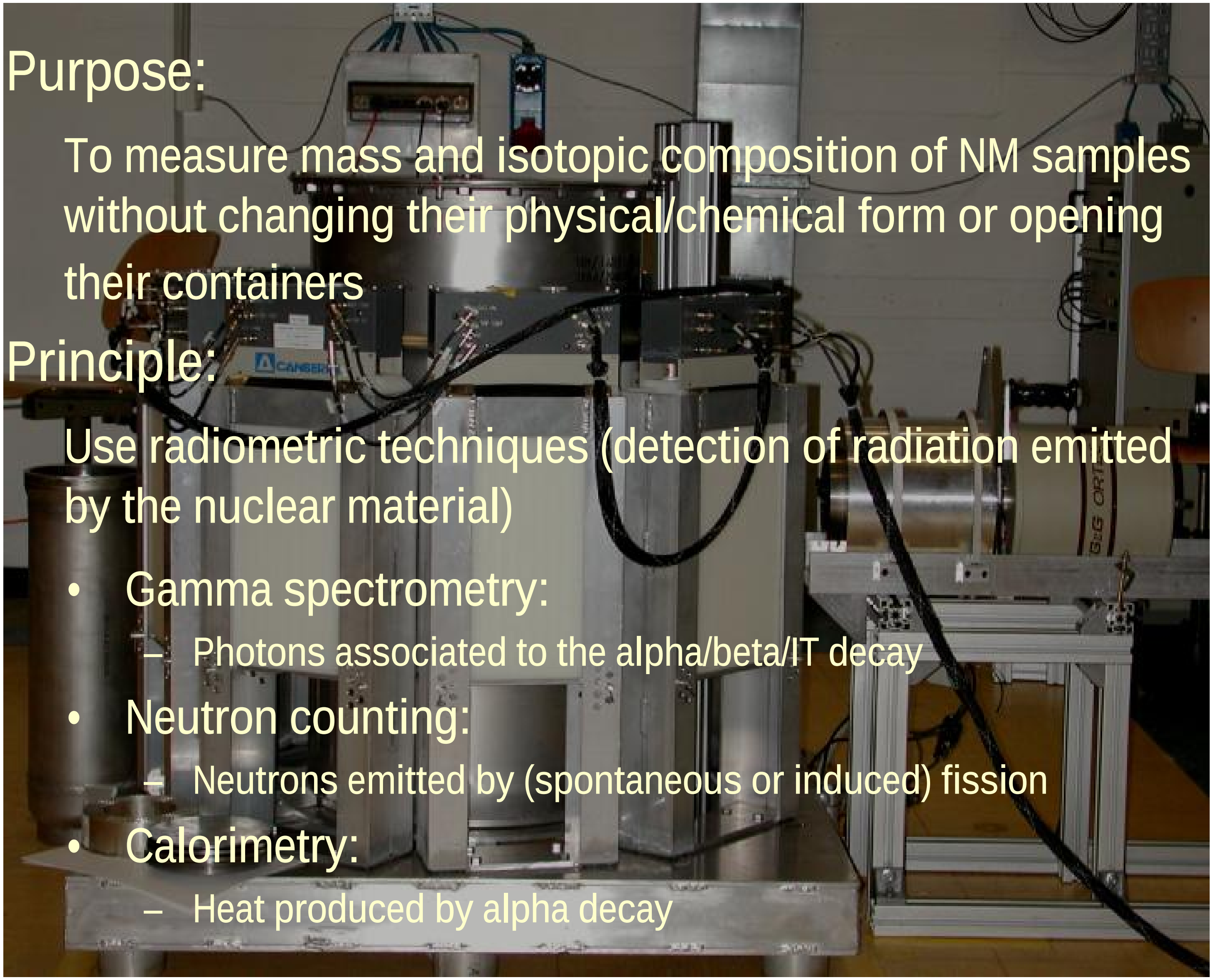
It determines the mass-to-charge ratio of ions, by ionizing the sample and separating ions of differing masses (f.i. in EM field) and recording their relative abundance by measuring intensities of ion flux.

Ion sources: Thermal Ionis., ICP, Glow Discharge, Secondary Ions,…

Mass analysers: magnetic sector, magnetic quadrupole, TOF,…

If a known quantity of a tracer is added to the solution (spike) the relative isotopic composition can give an absolute concentration determination (IDMS).

Non-Destructive Analysis (NDA)



Purpose:

To measure mass and isotopic composition of NM samples without changing their physical/chemical form or opening their containers

Principle:

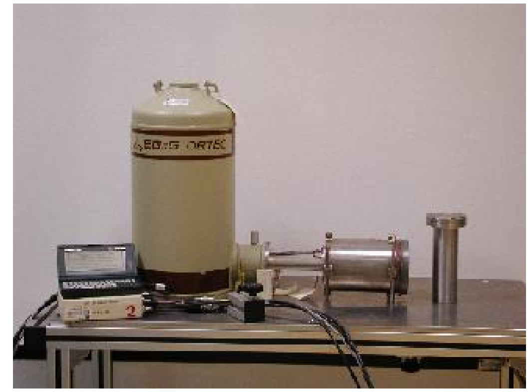
Use radiometric techniques (detection of radiation emitted by the nuclear material)

- Gamma spectrometry:
  - Photons associated to the alpha/beta/IT decay
- Neutron counting:
  - Neutrons emitted by (spontaneous or induced) fission
- Calorimetry:
  - Heat produced by alpha decay

Non-Destructive Analysis (NDA)

Gamma spectrometry:

Used to determine the uranium enrichment or the plutonium isotopics by deconvolution of the energy spectra of photons, whose energy is isotope specific.



Neutron counting:

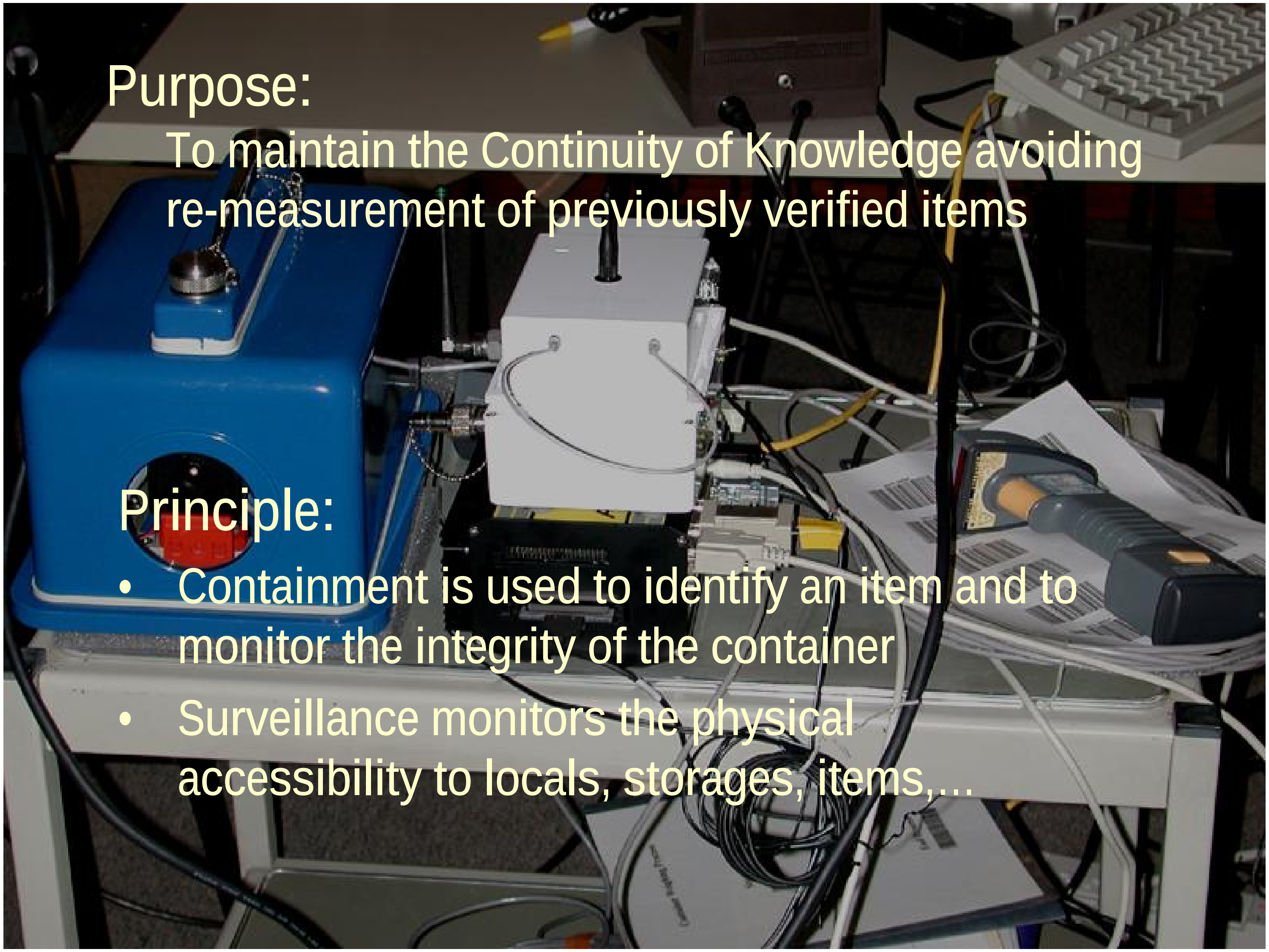
In passive mode it is used to determine the plutonium mass through detection of neutrons emitted by spontaneous fission of even isotopes (mostly Pu-240).

In active mode the U-235 mass can be deduced by the fission rate induced by an external neutron source.

The method requires a calibration with standards.

Isotopic composition is needed to pass from the mass of an individual isotope to elemental mass.

Containment & Surveillance (C/S)



Purpose:

To maintain the Continuity of Knowledge avoiding re-measurement of previously verified items

Principle:

- Containment is used to identify an item and to monitor the integrity of the container
- Surveillance monitors the physical accessibility to locals, storages, items,…

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Containment & Surveillance (C/S)

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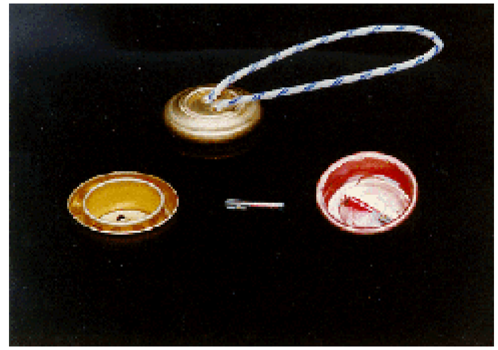
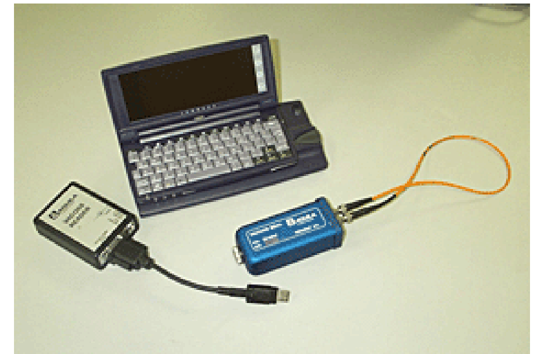
Seals

- Metallic caps
- Electronic seals
- Optical fiber seals
- Ultrasonic bolts
- Transponders





Surveillance

- Optical or digital cameras
- Laser range finder

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Safeguards techniques for undeclared activities

- Sensitive technologies
  - Enrichment
  - Reprocessing
- Inspection methods
  - Environmental sampling
    - Swipes (HPTA)
    - Wide area monitoring
  - Satellite monitoring
  - Open source information
  - Extended possibilities for inspections
    - Comprehensive information about nuclear fuel cycle
      - Past
      - Present
      - Future
    - Complementary access

Environmental sampling

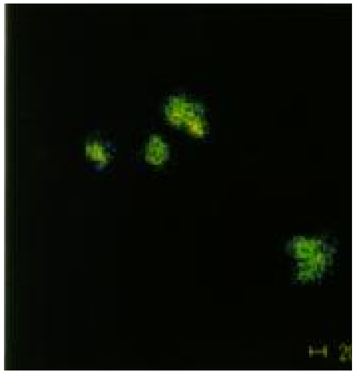
Purpose:

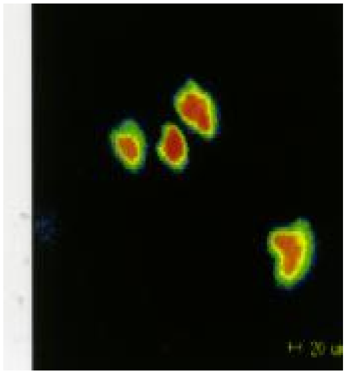
to detect clandestine plants or undeclared activities in declared plants

Principle:

Any process produces leaks.

The signatures of a clandestine process can be detected either in the environment (WAES) or taking swipes inside a plant (HPTA).





Technique:

Secondary Ion Mass Spectrometry (SIMS):

When a solid sample is sputtered by primary ions, a fraction of the particles emitted from the target is ionised. SIMS consists of analyzing these secondary ions with a mass spectrometer. Secondary ion emission by a solid surface under ion bombardment supplies information about the elemental, isotopic and molecular composition of its uppermost atomic layers or of a selected individual particle.

Open source information analysis

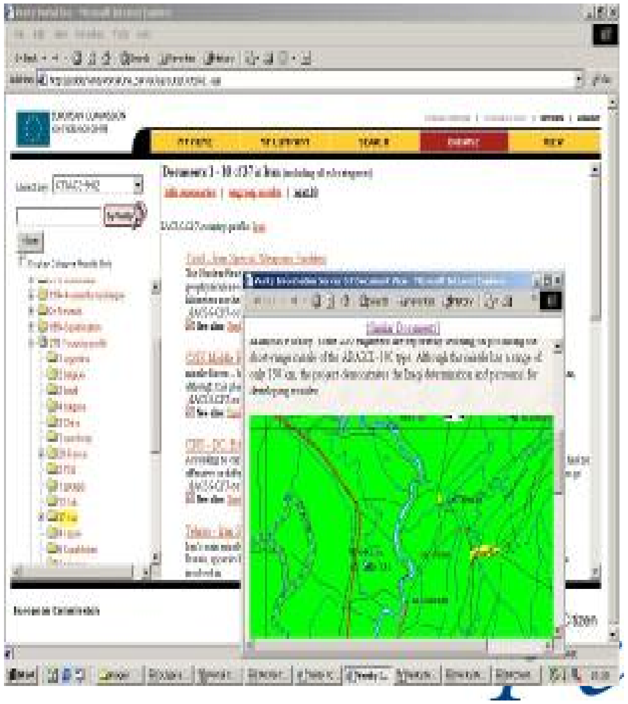
Purpose: to detect undeclared nuclear activities

Principle:

Survey, retrieval, storage and analysis of any kind of open information (newspapers, media broadcasts, S&T journals, publications, web sites, databases, images), that could be relevant to the comprehensive knowledge of nuclear activities in a country and possibly come to the conclusion of absence of undeclared activities.

Techniques:

- Dedicated tools for data mining (f.i. Web search engines)
- Automatic multilingual analysis of texts
- Satellite imagery
- Specialised databases (f.i. import/export control)
- Cross-correlation of information (expert analysis)
- Country profiles



Satellite imagery

Purpose:

to detect clandestine plants

Principle:

Detection of buildings with typical patterns characteristic of a nuclear installation and monitor the morphological evolution of a nuclear site